THE MAINTENANCE OF FERTILITY.

LIMING THE SOIL.

LIME AND CEREAL CROPS. LIME AND CLOVER. WHEN, WHERE AND HOW TO APPLY LIME.

OHIO
Agricultural Experiment Station.

WOOSTER, OHIO, U. S. A., MARCH, 1905.

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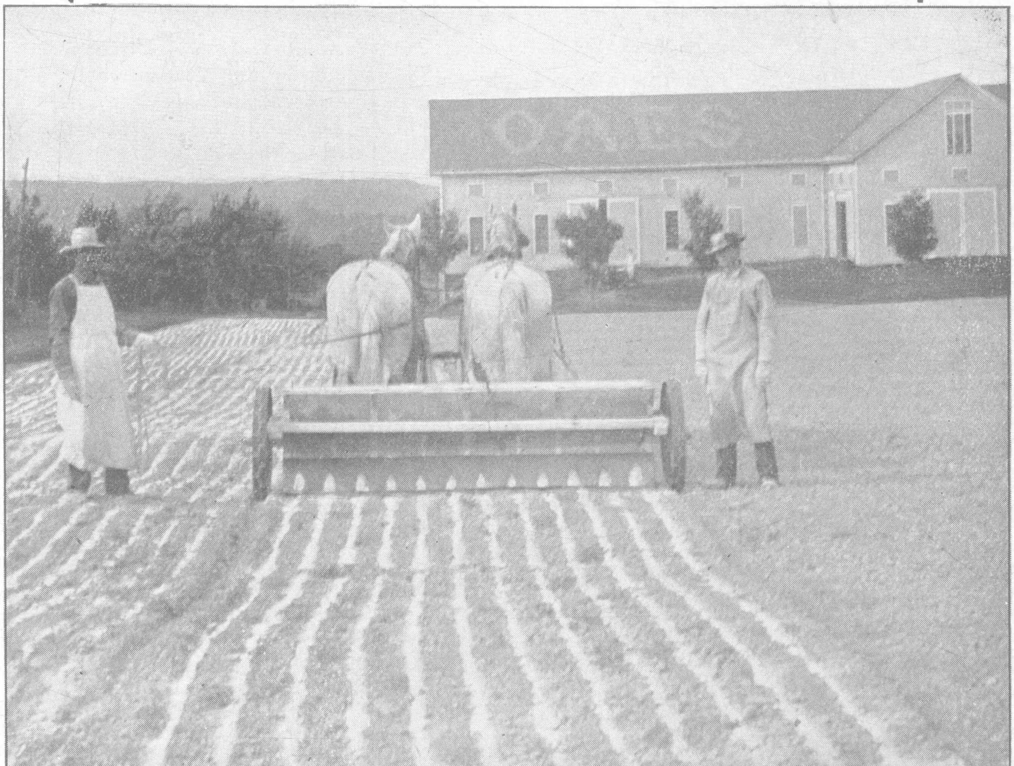

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BULLETIN

OF THE

Ohio Agricultural Experiment Station

NUMBER 159. MARCH, 1905.

THE MAINTENANCE OF FERTILITY.

LIMING THE SOIL.

BY CHAS. E. THORNE.

Lime is absolutely indispensable to the growth of plants, yet it is required in comparatively small amounts. The cereal crops, for example, take from the soil several times as much potash as lime, although soils usually contain as much lime as potash.

The abundance of lime is shown in the fact that water which has been in contact with the soil for any length of time is almost always hard, and yet a single grain of lime to the quart of water would supply as much lime as is found in an average crop of clover hay, although such a crop of clover takes from the soil several times as much lime as a similar yield of either of the cereal crops.

The estimated quantities of lime and some other substances found in average Ohio crops is given in the following table, the estimated composition of the crops being based upon the analysis of the entire plant—grain, stover and straw—by E. von Wolff, and the yields upon the statistics of crop production in Ohio for the ten years, 1890–'99:

POUNDS PER ACRE IN AVERAGE CROPS.

CROP	Nitrogen N	Phosphorus pentoxide P_2O_5	Potash K_2O	Lime CaO
Corn, 33 7 bushels	51	19	36	9
Oats, 29.3 "	32	12	31	8
Wheat, 14 6 "	30	9	17	5
Clover, 1.0 ton	41	8	44	40
Timothy 1.12 "	28	12	20	10

Lime, however, performs other functions in the soil than the supplying of plant food. One of the most important of these is the neutralizing of acidity. Acid soils are as yet unknown over many parts of Ohio; but in other sections, especially in the eastern half of the state, where the soil has largely been formed from the decomposition of sandstones and shales, this condition is becoming increasingly prevalent, and is manifested by the constantly enlarging areas in which clover is displaced by sorrel.

A partial explanation of the fact that acid soils do not furnish the best conditions for crop production is suggested by the investigations by Warington and others on nitrification, which have shown that this process is dependent upon the presence in the soil of a salifiable base; that is, of a base with which the nitric acid resulting from the nitrifying processes may unite, forming a salt. For such a base lime is the most suitable material, because of its comparative cheapness and of its importance as a constituent of living tissue. This means that some excess of available lime in the soil is necessary, over and above the bare needs of the growing crop for tissue building. On the other hand, these investigators have shown that an excessive application of quicklime to the soil may exert an exactly contrary effect, stopping the work of nitrification until the quicklime is converted into the less active form of carbonate.

Another function performed by lime is the liberation of plant food from compounds in the soil. If a little freshly burned lime be mixed with strong manure, such as hen manure or fresh stable manure, an odor of ammonia will become apparent. This means that the lime is entering into chemical union with certain constituents of the manure, and in doing so is liberating others, which pass off in the form of ammonia gas. If such lime be mixed with the soil a similar action will take place; the lime will unite with the decaying vegetation of the soil, liberating nitrogen in the form of ammonia. If a crop be growing upon the soil it may absorb a part of the escaping ammonia, and a larger yield will result; but this larger yield is produced at the expense of the soil stores of plant food, and if these stores are not maintained by liberal manuring or fertilizing, the soil will eventually fail to respond to lime, because all the material in it upon which lime can act has been destroyed, leaving the soil poorer than if no lime had been used.

TABLE I.—PLAN OF FERTILIZING IN 5-YEAR ROTATION.

PLOT	FERTILIZING MATERIALS.	QUANTITY PER ACRE.			
		ON CORN	ON OATS	ON WHEAT	TOTAL FOR ONE ROTATION
2	Acid phosphate	80	80	160	320
3	Potassium chloride (muriate of potash)	80	80	100	260
5	Sodium nitrate (nitrate of soda)	160	160	160	480
6	Acid phosphate Sodium nitrate	80 160	80 160	160 160	320 480
8	Acid phosphate Potassium chloride	80 80	80 80	160 100	320 260
9	Potassium chloride Sodium nitrate	80 160	80 160	100 160	260 480
11	Acid phosphate Potassium chloride Sodium nitrate	80 80 160	80 80 160	160 100 160	320 260 480
12	Acid phosphate Potassium chloride Sodium nitrate	80 80 240	80 80 240	160 100 240	320 260 720
14	Acid phosphate Potassium chloride Sodium nitrate	80 80 160	....	160 100 160	240 180 320
15	Acid phosphate Potassium chloride Sodium nitrate	....	....	160 100 160	160 100 160
17	Acid phosphate Potassium chloride Sodium nitrate	160 80 80	160 80 80	160 100 80	480 260 240
18	Barnyard manure	8 tons	....	8 tons	16 tons
20	Barnyard manure	4 tons	....	4 tons	8 tons
21	Acid phosphate Potassium chloride Linseed oilmeal	145 75 230	145 75 230	145 95 230	435 245 690
23	Acid phosphate Potassium chloride Dried blood	150 80 100	150 80 100	150 100 100	450 260 300
24	Acid phosphate Potassium chloride Ammonium sulphate	160 80 60	160 80 60	160 100 60	480 260 180
26	Raw bone meal Potassium chloride Sodium nitrate	55 80 150	55 80 150	55 100 150	165 260 450
27	Dissolved bone black Potassium chloride Sodium nitrate	70 80 160	70 80 160	70 100 160	210 260 480
29	Basic slag phosphate Potassium chloride Sodium nitrate	65 80 160	65 80 60	65 100 160	195 260 480
30	Acid phosphate Potassium chloride Tankage	80 80 170	80 80 170	80 100 170	160 260 510

The plan of fertilizing in this rotation is given in Table I. Under this plan potassium is applied in uniform quantity to all the plots except 2, 5 and 6, the carrier being potassium chloride (muriate of potash). On plot 21 allowance is made for the potassium carried in the linseed oilmeal.

Phosphorus is given in uniform quantity to all the plots, except 3, 5 and 9, where it is omitted, and 17, 21, 23 and 24, on which the quantity is doubled. The carrier of phosphorus is acid phosphate, except on Plot 26, where it is raw bone meal; Plot 27, where it is dissolved bone black, and Plot 29, where it is basic slag phosphate.

Nitrogen is furnished in sodium nitrate to all the plots except 2, 3 and 8, to which none is given, and 21, 23, 24 and 30, to which it is carried in linseed oilmeal, dried blood, sulphate of ammonia and tankage, respectively. On these plots and on No. 17, the quantity of nitrogen carried in the fertilizer is calculated to amount to 38 pounds per acre; on all the other plots, except No. 12, the rate of application is 76 pounds to the acre, while on Plot 12 it is increased to 114 pounds per acre.

Plots 17, 21, 23 and 24 have rec ived from the beginning of the experiment the same quantities each of nitrogen, phosphorus and potassium, but the nitrogen has been carried in different materials to the different plots. Plot 30 was not fertilized on the same plan during the first five years of the test, hence its results are not strictly comparable with those of the other plots.

Plots 11, 26, 27 and 29 have also received the same quantities of nitrogen, phosphorus and potassium, but the phosphorus has been given in different carriers.

The yard manure used on Plots 18 and 20 is taken from an open barnyard, that for corn having been exposed to the weather during the winter and that for wheat during the spring and early summer also. It is applied as a top dressing.

Not only does lime liberate nitrogen, but it may also act upon the potassium of the soil, converting it from insoluble combinations into those available as plant food. To a certain extent this may be a useful function, in the case of both nitrogen and potassium, but it may be carried to such excess by heavy and continuous liming that the plant food will be liberated more rapidly than the crops can make use of it and loss will occur from leaching.

A third function of lime is the amelioration of the texture of the soil. When heavy, plastic clay is wet, pressed into a cake and then dried, it becomes almost brick-like in texture; but if a small portion of quicklime be incorporated with the clay before manipulation it will crumble easily between the fingers after drying. For this purpose lime may be very usefully employed on many of the more refractory clay soils, using it at the rate of several tons per acre. Clays thus treated will become much more friable, will respond more readily to cultivation and manuring, and will not pack so readily under rain. The effect of such an application of lime will last for a number of years. It will be easily understood that the opening of the soil by a dressing of lime will facilitate the action of air, rain and other agencies by which the plant food of the soil is made available to crops. Loose, sandy soils may also be improved by liming, the lime rendering them more compact and more retentive of moisture.

For more than a century British and European farmers have used lime on the soil, and the effect of lime has been summarized in the proverbs—

"Lime enriches the father, but impoverishes the son;"

"Lime and lime without manure,
Will make both farm and farmer poor."

This does not mean that lime should never be used, nor that lime should be mixed with manure; but that lime and manure should follow each other in an intelligently ordered succession.

FIELD EXPERIMENTS WITH LIME.

For a number of years it has been increasingly difficult to secure a crop of clover on the Experiment Station farm. The seed germinates and at first the stand appears to be good, but when the wheat is taken off the growth of clover is found to be uneven, there being patches of good clover interspersed with areas on which the plants are stunted. These areas increase in size as the season progresses; the clover on them is largely destroyed during the winter following the seeding, and by spring there is usually but little clover left.

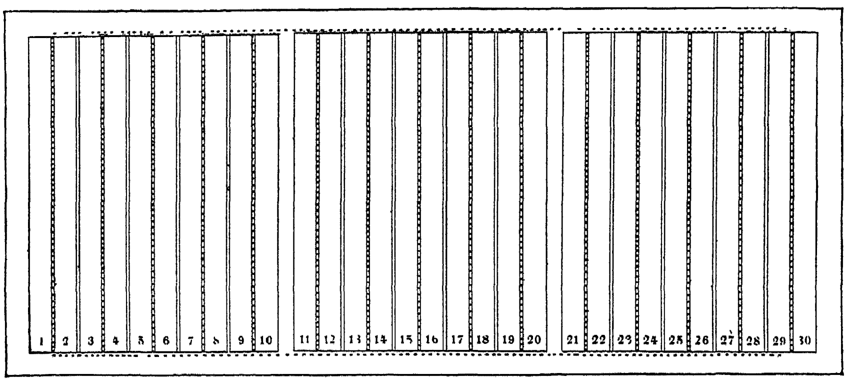
This difficulty is not confined to the Station farm, but is prevalent over a considerable part of North-eastern Ohio. The soil on which this trouble is experienced is generally found to give an acid reaction under the litmus test, and the poorer the clover the more pronounced is the indication of acidity.

There is an evident relation between the previous treatment of the soil and the present behavior of clover upon it. Land which has been brought under cultivation at a comparatively recent date, or which has been kept in good heart by liberal and frequent use of manure in a well planned crop rotation, is still producing fine crops of clover; but on lands which have been steadily cropped for half a century or more, with little manuring and a rotation of crops in which clover was grown but once in five or six years, and especially on those which have been stimulated to unusual production of cereals by the use of acid phosphate, without reenforcement by materials carrying nitrogen and potassium, there is a general and increasing failure of the clover crop.

One of the Station's experiments with fertilizers and manures is located upon land of this character, the farm on which the test is located having been in cultivation for three quarters of a century, and under tenant husbandry for many years before it came into possession of the Station.

In this experiment five tracts of land are employed, which, for convenience are named "Sections A, B, C, D, E, 5-crop Rotation." On these sections corn, oats, wheat, clover and timothy are grown, in the order named, the cropping being so planned that each crop is represented every season. Each section is subdivided into 30 one-tenth-acre plots, the plots being 16 feet wide by 16½ rods long, and separated by dividing spaces two feet wide. At the beginning of the experiment each plot was plowed separately, the dead furrows falling in the dividing spaces, and this separate plowing is repeated every five or ten years, thus keeping the plots slightly ridged. At other times the plowing is across the plots. The object of ridging the plots is two-fold: to provide for uniform removal of surplus water in heavy rains and to keep a dead furrow between the plots, in order to prevent the plants growing on one plot from profiting by the fertilizers distributed over the plot adjoining. That this object is quite effectually accomplished will be seen by the accompanying illustrations. (See Fig. 5).

The whole area under experiment was tile drained in 1893, the drains being laid 30 inches deep and under alternate dividing spaces between the plots on all the sections except B, where, owing to the topography of the land, they were laid lengthwise of the section; but here, as in the other cases, they were laid 36 feet apart. The accompanying diagram shows the plan of plotting and drainage.



LIME ON CORN.

The experiment was begun in 1894. In 1900 the west half of Section E was limed at the rate of 2,000 pounds per acre (not 1,000 pounds, as erroneously stated in Bulletin 141) the lime being ordinary stone lime, such as builders use, which was spread across the plots, so that the west half of each plot received a dressing of lime. The lime was applied after the land had been prepared for corn, being slacked on the ground, spread over the surface by hand and harrowed in before the corn was planted.

As succeeding sections have come under corn the liming has been repeated, until now the entire experiment has received lime on the west half of the plots. In 1902, and since, the lime used has been a ground quick-lime, which has been stirred into the soil without slacking. For the crop of 1904 the lime was applied the preceding fall, the land having grown soy beans the two previous seasons, because of the total failure of the clover crop. The corn on the limed and unlimed ends of the plots has been harvested separately for the crops of 1900, 1901, 1902 and 1904. In 1903 the corn was so injured by grub worms that it did not seem advisable to attempt a comparison between the two ends of the plots.

In Table II is given, for the four crops, the average total yield of grain per acre for the limed and unlimed land respectively, the average increased yield of the limed over the unlimed land, and the average increase due to the fertilizers on the limed and unlimed land, this increase from the fertilizers being found by comparing the yield of each fertilized plot with that of the two unfertilized plots between which it lies, on the assumption that variations in the yield of the unfertilized plots are likely to be generally due to progressive variations in the soil, and thus that if, for example, Plots 1 and 4, unfertilized, should yield 30 and 33 bushels per acre, respectively, the yields of Plots 2 and 3, had they not been fertilized, would probably have been 31 and 32 bushels, respectively.

In making the comparisons in this experiment the limed and unlimed portions of each tract of land are of course treated as separate tests, the effect of the fertilizer on unlimed land being ascertained by comparing with the unlimed ends of the check plots, and the effect on limed land by comparison with the limed ends.

The table shows that there has been a marked increase in the yield of the limed land over that left without lime, the average gain for lime being nearly 10 bushels per acre. It will be observed that there is very little difference in the effect of the fertilizers on the corn crop on the limed and unlimed land, except on Plot 24, on which nitrogen is applied in sulphate of ammonia, thus giving this plot a double portion of sulphuric acid. On this plot the increase from the fertilizer is smaller by 6 bushels on the unlimed than on the limed land. The work must go further, however, before definite conclusions on such points as this will be justified.

TABLE II.—AVERAGE YIELD OF CORN AND INCREASE FROM FERTILIZERS FOR THE 4 YEARS, 1900, 1901, 1902 AND 1904.

PLOT NO	FERTILIZERS PER ACRE FOR COMPLETE ROTATION.	YIELD PER ACRE		GAIN FOR LIME	INCREASE FROM FERTILIZERS	
		LIMED	UN-LIMED		LIMED	UN-LIMED
		Bus.	Bus.	Bus.	Bus.	Bus.
1	None	40.61	29.25	11.36	.....	.....
2	Acid phosphate. 320 lbs	51.53	41.48	10.05	11.10	12.30
3	Potassium chloride 260 lbs	41.26	28.21	13.05	[1] 2.45	[1] 3.42
4	None	40.09	29.05	11.04	.....	.....
5	Sodium nitrate, 480 lbs	45.25	35.77	9.48	5.10	6.76
6	Acid phosphate and sodium nitrate	56.16	48.48	7.68	15.95	19.51
7	None	40.26	28.93	11.33	.....	.....
8	Acid phosphate and potassium chloride	56.75	44.18	12.57	17.18	14.77
9	Potassium chloride and sodium nitrate	47.87	38.70	9.17	8.99	8.81
10	None	38.19	30.37	7.82	.....	.....
11	Acid phos. potassium chloride and sodium nitrate	61.00	53.50	7.50	22.16	23.42
12	Acid phos. potassium chloride and sodium nitrate [2]	63.94	55.30	8.64	26.45	25.51
13	None	40.14	29.51	10.63	.....	.....
14	Acid phos. potassium chloride and sodium nitrate [3]	59.25	48.71	10.54	19.67	19.66
15	Acid phos. potassium chloride and sodium nitrate [4]	46.43	36.34	10.09	7.41	7.75
16	None	38.46	28.12	10.35	.....	.....
17	Acid phos. potassium chloride and sodium nitrate [5]	63.48	48.98	14.50	23.32	20.12
18	Yard manure, 16 tons per acre	64.19	54.23	9.96	22.34	24.68
19	None	43.55	30.34	13.21	.....	.....
20	Yard manure, 8 tons per acre	54.75	44.80	9.95	13.49	15.61
21	Acid phos. potassium chloride and linseed oil meal [6]	59.88	48.24	11.64	20.91	20.20
22	None	36.67	26.89	9.78	.....	.....
23	Acid phos. potassium chloride and dried blood [6]	60.14	49.32	10.82	21.93	20.61
24	Acid phos., potas. chloride and ammonium sulph. [6]	63.60	48.28	15.32	23.85	17.75
25	None	41.30	32.36	8.94	.....	.....
26	Raw bone meal, potass. chloride and sod. nitrate [7]	60.91	53.14	7.77	20.29	20.56
27	Diss. bone black, potass. chloride and sod. nitrate [7]	61.09	54.64	6.45	21.15	21.84
28	None	39.25	33.02	6.23	.....	.....
29	Slag phos. potassium chloride and sodium nitrate [7]	58.36	52.66	5.70	19.10	19.64
30	Acid phosphate, potassium chloride and tankage	54.50	47.23	7.27	15.24	14.21

1 For 1900, 1901 and 1902 only.

2 720 lbs. nitrate soda on Plot 12.

3 Fertilized on corn and wheat only.

4 Fertilized on wheat only.

5 480 lbs. acid phosphate and 240 lbs nitrate of soda.

6 Carrying phosphorus and nitrogen equivalent to Plot 17.

7 Carrying phosphorus and nitrogen equivalent to Plot 11.

Taking the other 10 plots to which complete chemical fertilizers, carrying nitrogen, phosphorus and potassium, are applied to corn, we find that the average increase from fertilizers on the limed land has been 21 bushels per acre and on the unlimed land, 20.6 bushels, an average difference of less than half a bushel per acre.

The results of this test may be more clearly brought out by grouping the plots according to the different quantities of nitrogen in the fertilizer, as shown in Table III. It appears from this table that the limed end of Plot 2, receiving acid phosphate, has yielded 10.05 bushels of corn per acre more than the unlimed end, and that the acid phosphate has made a further increase on the limed end of 11.10 bushels, raising the total increase from lime and fertilizer to 21. 15 bushels, as compared with an increase of 12.30 bushels from acid phosphate without lime.

TABLE III.—AVERAGE YIELD OF CORN AND INCREASE FROM LIME AND FERTILIZERS FOR THE 4 YEARS, 1900, 1901, 1902 AND 1904.

TREATMENT.	PLOTS.	YIELD PER ACRE		GAIN FOR LIME	INCREASE FROM FERTILIZERS	
		LIMED	UN-LIMED		LIMED	UN-LIMED
		Bus.	Bus	Bus.	Bus.	Bus.
Unfertilized		39.85	29 78	10 07	.....	.....
Without nitrogen:						
Phosphorus alone, in acid phosphate	2	51 53	41 48	10.05	11.12	12.30
Potassium alone, in the muriate	3	41 30	37.45	6.95	4 04	8.24
Phosphorus and potassium	8	56 75	44 18	12.57	17.18	14.77
Nitrogen 76 pounds:						
Nitrogen alone, in nitrate of soda	5	45.25	35.77	9.48	5.10	6.76
" with phosphorus	6	56.16	48 48	7 63	15 95	19.51
" with potassium	9	47 87	38 70	9 17	8.99	8.81
" with phosphorus and potassium	11,26.27,28	60 34	53 48	6 86	20.67	21.3
Nitrogen 114 pounds:						
" with phosphorus and potassium	12	63 94	55.30	8.64	26.45	25.51
Nitrogen 38 pounds:						
" with potassium and larger quantity of phosphorus	17,21 23 24	61 77	48 70	13.07	22.50	19.67
Yard manure, 8 tons each on corn and wheat	18	64 19	54 23	9.96	22 34	24.68
" " 4 " " " "	20	54.75	44.80	9.95	13.49	15.61

Where muriate of potash has been used alone on the unlimed land (Plot 3) it has produced very little increase of crop, and it has added but little to the effectiveness of acid phosphate (Plot 8) but when lime has followed muriate of potash, whether the latter has been used alone or in combination with acid phosphate, a marked increase due to the lime is apparent.

Taking the second section of this table, we see that a moderate addition of nitrogen to the fertilizer has produced a marked increase of crop, an increase somewhat greater on the limed than on the unlimed land in all cases, and especially so when the nitrogen has been carried in ammonium sulphate.

From the third section of the table it appears that larger applications of nitrogen have further increased the total yield of crop on the unlimed land, without causing any additional increase on the limed land, thus reducing the effect apparently due to the lime alone. The still larger application of sodium nitrate, on Plot 12, has slightly increased the yield on both limed and unlimed land, but the barn-yard manure appears to have been relatively more effective on the unlimed land, thus suggesting that the liming, following so closely after the manuring as it did in this experiment, may have caused some loss of effectiveness in the manure.

Taking the results as a whole, it would seem that the lime has performed two distinct offices in this test: In the first place it has increased the yield by an average of about 10 bushels per acre, or 30 percent of the unfertilized yield. This it must have done in one or both of two ways: either it has furnished a needed element of plant food to the growing crop, or else it has rendered the plant food already in the soil more available, either by direct chemical action of the lime itself on the soil stores of nitrogen, phosphorus and potassium, or by opening up the soil and giving the air, water and frost a better opportunity to reach these stores and prepare them for plant nutrition.

The other office performed by the lime seems plainly to have been the setting up of conditions favorable to the growth in the soil of the micro-organisms, by which the stores of organic nitrogen are gradually converted into available form through the process of nitrification. This is indicated by the fact, that the giving of large quantities of available nitrogen in the fertilizers appears to have reduced the effect ascribable to lime, whereas this effect seems to have been augmented by fertilizers containing little or no nitrogen.

LIME ON CLOVER.

Only one crop each of oats and wheat in this test has been separately harvested. These results will be discussed further on. The first crop of clover to come under the experiment was harvested in 1903, and the average yields of this crop and that of 1904 are given in Table IV, the results being grouped for purpose of comparison.

TABLE IV.—AVERAGE YIELD OF CLOVER HAY, AND INCREASE FROM LIME AND FERTILIZERS, 1903 AND 1904.

	FERTILIZING ELEMENTS PER ACRE IN COMPLETE ROTATION.	PLOT	YIELD PER ACRE		GAIN FOR LIME	INCREASE FROM FERTILIZERS	
			LIMED	UN-LIMED		LIMED	UN-LIMED
		No.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
I.	Phosphorus 20 lbs. (in acid phosphate).	2	2,909	1,254	1,655	562	* 170
	Potassium 108 lbs. (in potassium chloride).......	3	2,256	1,155	1,101	* 30	* 64
	Phosphorus 20 lbs. and potassium 108 lbs.	8	3,289	1,127	2,162	1,124	36
II.	Nitrogen 38 lbs. with phosphorus 30 lbs. and potassium 108 lbs:—						
	Nitrogen in sodium nitrate......................	17	3,413	1,912	1,501	1,678	924
	" " linseed oilmeal..........	21	3,019	1,104	1 915	1,197	278
	" " dried blood...........................	23	3,089	1,031	2,003	1,267	295
	" " ammonium sulphate................	24	3,119	1,140	1,979	1.281	316
	Average of 17, 21, 23 and 24.................		**3,160**	**1,309**	**1,851**	**1,356**	**453**
III.	Nitrogen 76 lbs, in sodium nitrate:—	5	2,528	1,321	1,207	339	289
	" " with phosphorus 20 lbs........	6	3,342	1,701	1,641	1,189	651
	" " with potassium 108 lbs........	9	2,645	1,400	1,245	430	285
	Nitrogen 76 lbs., phosphorus 20 lbs. and potassium 108 lbs:—						
	Phosphorus in acid phosphate..............	11	3,370	2 947	423	1,165	1,815
	" " raw bone meal.................	26	3,330	2,480	850	1,586	1,553
	" " dissolved bone black.........	27	2,837	1,895	942	1,203	903
	" " basic slag phosphate.........	29	2,819	2,473	346	1,294	1,441
	Average of 11, 26, 27 and 29......................		**3,089**	**2,449**	**640**	**1,312**	**1,428**
IV.	Nitrogen 114 lbs. in sodium nitrate, with phosphorus, 20 lbs. and potassium 108 lbs:—	12	3,712	2,542	1,170	1,567	1,417
V.	Barnyard manure, 16 tons.......................	18	3,905	2,402	1,503	2,109	1,418
	" " 8 "	20	2,820	1.426	1,394	981	524
	Average unfertilized yield.................		1,981	1,061	920	.. . ...	....

* Decrease.

The first division of Table IV shows that, where acid phosphate or muriate of potash has been used alone on unlimed land, the yield of hay has been actually less than that on the adjoining check plots which received no fertilizer, and where the two were used in conjunction there was no appreciable increase in yield. The table, in fact, does not tell the whole story, as timothy was sown with the clover, and most of what hay was harvested, from Plots 2 and 8

FIG. 1. A characteristic view of the behavior of clover on unlimed land in the neighborhood of the Experiment Station. The stand here was originally perfect, as shown by Fig. 2.

FIG. 2 The limed portion of the same tract of land shown in Figure 1, both being portions of Section B., 5-year rotation, at the Experiment Station, and both having had exactly the same treatment as to cropping and seeding with clover.

FIG. 4. Limed end of Plot 2, Sectiou E, June, 1902.
A fair crop of clover, with considerable "White-top".

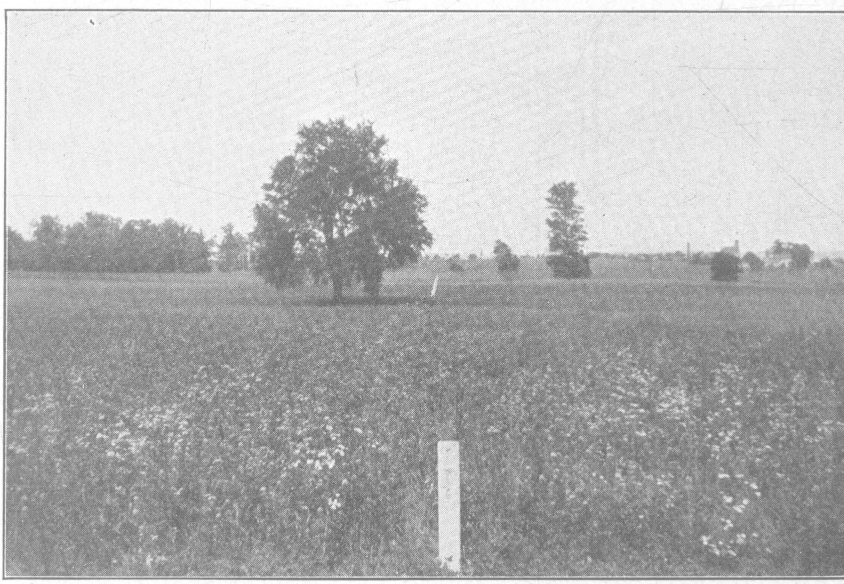


FIG. 3. Unlimed end of Plot 2, Section E, June, 1902.
The growth is timothy, with only an occasional clover plant.

especially, consisted of timothy and weeds. (See Figs. 3 and 4.) When lime was added to these plots, however, the yield of Plot 2, receiving acid phosphate only, was materially increased, while that of Plot 8, receiving both acid phosphate and muriate of potash, was brought up to a point as high as the average of the plots which received not only these two materials but also carriers of nitrogen. This point, together with the fact that the increased growth due to lime was chiefly clover, is brought out by Figures 5 and 6, which show the unlimed and limed ends of Plot 8, taken a few weeks after the wheat had been harvested on Section A, in 1904.

Referring to the second division of the table, we see that where a complete fertilizer has been used, carrying nitrogen as well as phosphorus and potassium, there has been considerable increase of crop on the unlimed land when the nitrogen was carried in sodium nitrate, but when the carrier was oilmeal, dried blood or ammonium sulphate the unlimed yield has been no greater than when no nitrogen was added. On all these plots, however, the effect of the fertilizers has been greatly augmented by the use of lime, the increase from the fertilizers, over and above that due to the lime itself, being nearly twice as great on the limed end of the plot receiving sodium nitrate as on the unlimed end, and more than five times as great on the other plots.

The third division of the table shows that a large application of sodium nitrate has produced but little effect on the unlimed land when used alone or with potassium only, and but a moderate increase when used with phosphorus only, but when used in combination with both phosphorus and potassium the yield on the unlimed land has been more than doubled, and the further increase due to lime alone has been small. Plot 11, treated with sodium nitrate, muriate of potash and acid phosphate, shows the largest yield on the unlimed land of any plot in the series; but this yield has consisted largely of timothy, there being conspicuously more clover on Plots 26 and 29, receiving non-acidulated phosphates, than on either 11 or 12.

The further increase of nitrogen, to 114 pounds per acre, on Plot 12, has produced no further increase in the total weight of hay on the unlimed land than that found on Plots 26 and 29, and apparently not so great an increase as that on Plot 11, but the increase on the limed land has been decidedly greater. It will be observed that the quantities of phosphorus and potassium are the same on Plots 11 and 12, the only change being in the amount of nitrogen. Finally, the large application of barnyard manure, given

FIG. 5. Unlimed end of Plot 8, Section A, July, 1804. Observe the large growth (which was chiefly clover on a part of Plot 7, unfertilized on the left, and Plot 9, fertilized, on the right. The stubbles on this end of plot 8 were not hid by th clover at the end of the season.

FIG. 6. Limed end of Plot 8, Section A, July 1904. Figures 5 and 6 were taken the same day. Note the dense, vigorous growth of clover, almost completely hiding the wheat stubble.

to Plot 18, produces practically the same increase of hay on the unlimed land as that given by the complete chemical fertilizer containing 76 to 114 pounds nitrogen per acre, while the increase from the manure on the limed land is greater than that from any of the chemical fertilizers. The 16 tons of yard manure used in these tests is estimated to contain about 160 pounds of nitrogen, with more phosphorus but less potassium than the quantities carried in the fertilizers applied to the other plots in this experiment. (See Figures 7 and 8.)

Referring to the plan of the experiment, it will be seen that manure is applied to corn and wheat, and in this test it is applied to the surface after plowing in the case of both corn and wheat, being merely stirred into the surface with the disc harrow. This method of application exposes the manure to severe loss when followed by lime, as it has been on the corn crop, but no such loss would occur with the wheat, as the lime has all been used on the corn. It would seem that the difference in effect of manure on the limed and unlimed portions of the land on the corn and clover crops might be thus explained.

Reviewing the table as a whole, we see that on the unlimed land the average unfertilized yield of hay has been approximately half a ton per acre, and no fertilizer, nor combination of fertilizers has materially increased this yield, except when used in conjunction with either lime or a large application of nitrogen. Lime alone has nearly doubled the unfertilized yield, and has more than doubled the yield obtained from fertilizers containing no nitrogen, or from other carriers of nitrogen than nitrate of soda or barnyard manure. Nitrate of soda appears to have materially increased the yield in all cases, but it has required the help of some carrier of phosphorus at least, if not also of potassium, to produce the maximum yield.

Acid phosphate and muriate of potash, used separately or in combination, in the absence of lime or nitrate of soda have apparently produced an injurious effect upon the clover, but when used in combination with each other and followed by lime these materials have produced almost the maximum yield.

It appears therefore that, on the soil under experiment, the presence of an abundant supply of available lime, together with phosphorus and potassium, has enabled the clover plant to make a normal growth without the assistance of any nitrogenous fertilizer; but that, in the absence of lime, the clover must be supplied with combined nitrogen, and that in large quantity, as well as with phosphorus and potassium.

FIG. 17. Unlimed ends of Plots 17 and 18, Section B, June, 1904. In the middle ground is seen the clover standing on the limed ends of these plots. Observe the imperfect stand of clover on Plot 18, even after a dressing of 8 tons of barnyard manure, applied twice every five years.

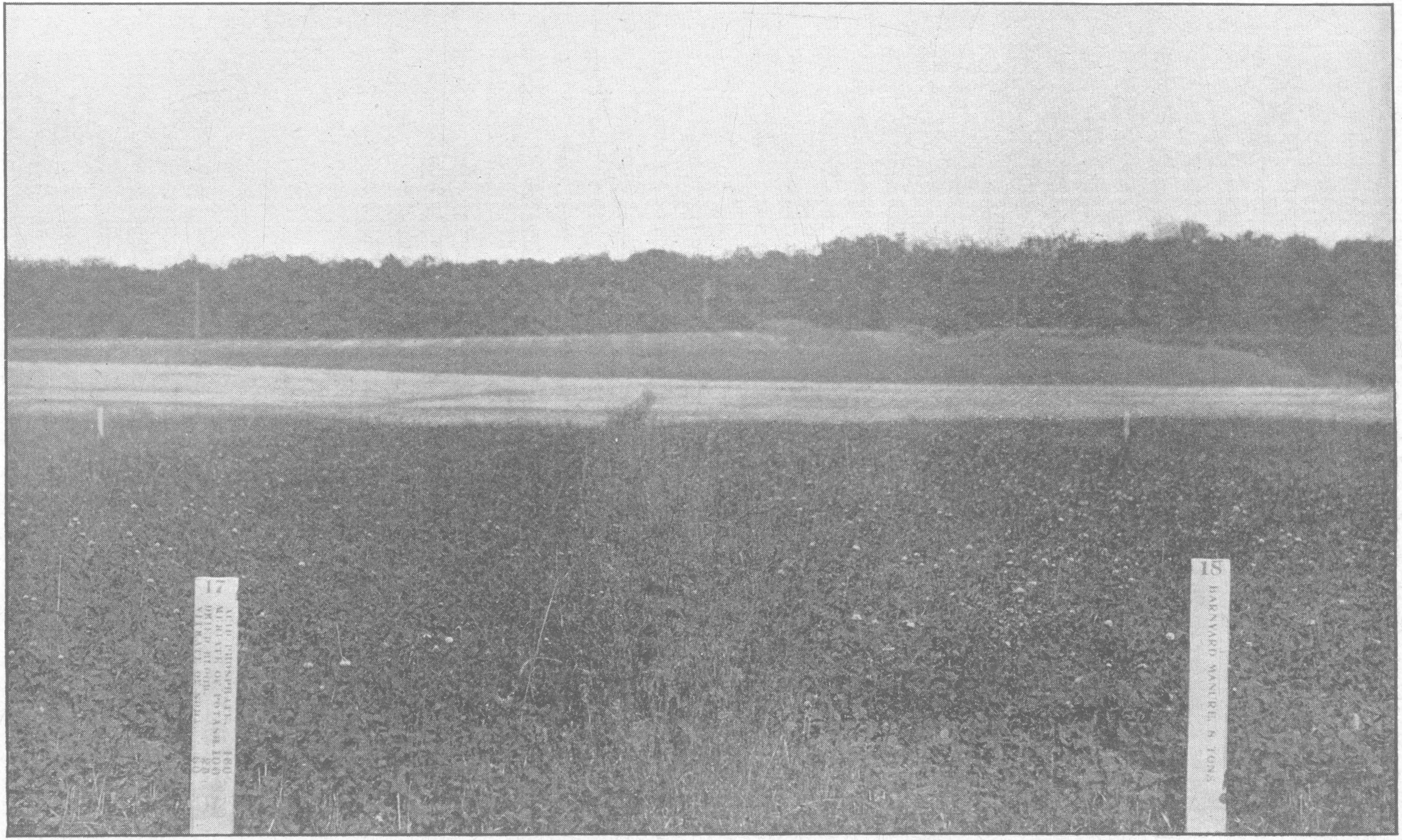


FIG. 8. Limed ends of Plots 17 and 18, Section B, June, 1904.

The superior effect produced by sodium nitrate, as compared with other carriers of nitrogen, suggests the query whether this effect may not be largely due to the liberation of soda from this compound and the neutralization of the soil acids by this soda. The quantity of sodium nitrate applied per acre to Plot 12, in the course of a 5-year rotation, would carry nearly 200 pounds of sodium, equivalent to 263 pounds of sodium oxide or soda, combined with 114 pounds of nitrogen; but average analyses indicate that not more than 20 pounds of sodium would be found in the entire produce of this plot for the 5 years, as against 280 pounds of nitrogen. There can be no doubt that, in the assimilation of plant nutrients, the chemical compounds in which these nutrients are found in the soil are broken up in the dilute solutions which are absorbed by the plant roots, and transferred into other combinations. In other words, the sodium nitrate, which the experiments above outlined show to have exerted such a powerful influence on the growth of crops, is not stored in the tissues of those crops as sodium nitrate, but its nitrogen is appropriated to the building up of the albuminoid tissues of the plant, while the excess of sodium is left in or returned to the soil to be there recombined in some other form.

This excess of sodium may in part explain the better effect on clover of sodium nitrate than of the other nitrogen carriers employed in these experiments, since the sodium might furnish the salifiable base essential to the existence of the nitrifying organisms, but that it alone has not been sufficient is shown by the fact that even after the largest applications of nitrate of soda a further gain is produced by the addition of lime.

It is true, however, that lime is needed as lime for purposes of direct plant food in larger measure by clover than by most other agricultural plants, so that we should expect an actual deficiency of lime in the soil to be manifested by clover before other crops would show it.

EFFECT OF LIME ON OATS AND WHEAT.

The oats crop of 1901, following the limed corn crop of the previous year, was harvested separately on the limed and unlimed land, but there was considerable irregularity in the results, and it was assumed that this irregularity was due chiefly to inequality of soil on the two ends of the plots, rather than to any effect of the lime. Acting on this assumption, the wheat crop following was only harvested separately on the first ten plots, and neither oats nor wheat was separately harvested in 1903 and 1904, the great pressure of work at harvest time and the large amount of labor involved in the separate harvesting making it seem inadvisable to undertake such work unless a distinct object were in view.

At no time has there been so conspicious a difference in the growth of the cereal crops on the limed and unlimed land as in that of the clover, and it was not until the corn and clover crops of 1904 had been harvested and the several years' work with lime studied in detail, that it was discovered that the apparent irregularities which had been observed in the earlier harvests were, in a large degree, the manifestations of a general principle, modified, it is true, by differences in soil and by seasonal peculiarities. Taking the first four unfertilized plots of Section E, on which this test was begun, we find that the average yield of the limed ends exceeded that of the unlimed by 14.87 bushels of corn in 1900, 12.89 bushels of oats in 1901 and 7.50 bushels of wheat in 1902, and there were similar differences in the yields of the fertilized plots lying between. That these differences were not altogether due to natural superiority of soil on the limed ends of the plots has been gradually brought out by the successive corn crops. Of the 120 plots on which the corn has been separately harvested in this test, only 8 show as large a yield on the unlimed as on the limed portions. Moreover, other tests, with corn and wheat, are adding further evidence of the improvement in yield following the use of lime.

LIME ON WHEAT GROWN CONTINUOUSLY ON THE SAME LAND.

In the fall of 1893 an experiment was begun in the continuous culture of wheat on the same land, an acre of land being set apart for that purpose on the farm at Wooster. In the fall of 1899 half this acre was dressed with lime, applied at the rate of 2,000 pounds per acre and across the plots, as in the test above described, the lime being applied to the surface and harrowed in after the land had been prepared for wheat and before the wheat was sown. The crops which followed this liming were separately harvested, and showed a considerably larger yield on the limed land than on that left without lime. After three years, namely: in the fall of 1902, the other half acre was limed, the object being to make sure that the increase indicated for the lime might not have been due to a greater natural fertility of the section first limed and, if this proved not to be the case, to place the soil as far as possible in a normal condition for further comparison of the different methods of fertilizing. The plan of fertilizing and the quantities of grain per acre harvested from each plot on the unlimed and limed portions are given in Table V for the crops of 1900, 1901, 1902 and 1903. The crop of 1904 in this experiment was so poor that it was not deemed advisable to harvest the two ends of the plots separately.

TABLE V.—EFFECT OF LIME ON WHEAT GROWN IN CONTINUOUS CULTURE.

PLOT.	1900		1901		1902		1903	
	LIMED	UNLIMED	LIMED	UNLIMED	LIMED	UNLIMED	LIMED	UNLIMED
	GRAIN PE ACRE.							
	Bus.	Bus.	Bus.	Bus.	Bus.	Bus.	Bus.	Bus.
1	2.83	1 33	14 33	4.50	15.33	9 66	13 83	11 17
2	20.00	16.00	23.33	18.16	28.00	24.00	28.33	24.67
3	10.50	7.16	22 67	14.83	26.50	22.66	23.00	20.33
4	3 33	1.67	14.00	7.16	17.66	13 00	* 12 00	12.67
5	9.50	7.67	20.33	12.50	21.17	16.00	* 19.00	20.67
6	15 67	12.67	23.50	16.33	24.00	18 17	* 25.17	27.50
7	* 2.67	3.17	12 83	8.50	17.33	15 00	13.83	12.33
8	17.33	15.00	25.50	20.83	37.00	28.17	* 29.83	33.83
9	* 13.33	13.33	23.50	19.00	33.00	30.33	* 29.17	29.17
10	* 2.33	2.67	12 17	7 16	15.00	10.33	11.00	10 33
Average..........	9.749	8 067	19 216	12.897	23.499	18 732	20 516	20.267
	STRAW PER ACRE.							
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
1	390	220	1,840	790	1,180	960	* 1,350	1,570
2	1 800	1,440	3,300	1,610	2,820	2,320	3 060	2,700
3	1,010	650	2,760	1,710	1,970	1,780	* 2,080	2,100
4	380	250	1,740	890	1,640	1,220	* 1,160	1,200
5	970	660	2,440	1,610	1,830	1,540	2,060	2,020
6	1,440	1,180	2,730	2,040	2,160	1,930	2,930	2,910
7	* 300	310	1,530	1,190	1,320	1,220	1,530	1,060
8	1,600	1,580	3,430	3,050	3,140	2,790	* 3,350	3,510
9	* 1,200	1,340	2,790	2,660	2 100	2,380	2,870	2,750
10	* 240	340	1,310	730	1,220	960	* 940	1,000
Average..........	933	797	2,387	1,628	1.968	1,710	2,133	2 082

This table shows that the first crop after liming, that harvested in 1900, gave an average yield on the limed land greater by a bushel to the acre than that on the unlimed, but this increase was irregular, 3 plots of the 10 showing yields on the unlimed ends (indicated by *.) equal to or greater than those on the limed ends. This crop was seriously injured by Hessian fly, but we were not able to discover that the lime had any effect on the fly.

The next crop, that of 1901, shows a marked increase in yield of the limed land over that left unlimed, the average gain being more than 6 bushels per acre.

The crop of 1902 also shows a decidedly larger yield on the limed than on the unlimed land, the average gain for lime amounting to 4¾ bushels.

The crop of 1903 shows a small average gain on the limed land, but the yields are nearly balanced, half the plots showing unlimed yields equal to or greater than those on the limed ends; but it must be remembered that the "unlimed" land for this season is that which had been classed as "limed" in the three preceding harvests, thus showing that the increased yields following the liming had certainly been due to the lime.

In the fall of 1903 lime was again applied directly to wheat in another experiment, the object being to contrast the ground quick-lime which we had been using up to that date with a slacked or "hydrated" lime which is being sold as a fertilizer. Both kinds of lime were applied shortly before sowing the wheat, at the uniform rate of 2,000 pounds per acre, and harrowed into the surface. Three plots were left without any fertilizer; the other plots were dressed with a fertilizer made up to contain about 4 percent "ammonia," 12 percent "phosphoric acid" and 3 percent "potash," and applied at the rate of 400 pounds per acre to each plot. The results of this test are given in Table VI.

TABLE VI. COMPARISON OF QUICK-LIME AND HYDRATED LIME.
EFFECT OF LIME ON WHEAT.

PLOT	TREATMENT.		YIELD PER ACRE	
1	No lime	No fertilizer	16 46	bus
2	Hydrated lime		14 62	"
3	No lime		16.21	"
13	No lime	400 lbs complete fertilizer	27.21	"
14	Hydrated lime		26.04	"
15	Quicklime		25.75	"
16	No lime		29 25	"
17	Hydrated lime		27 42	"
18	Quicklime		26.42	"
19	No lime		25.83	"

It will be observed that the yield of wheat is smaller on every limed plot than on the average of the unlimed plots between which it lies.

The clover following this wheat showed a considerably better growth after harvest on the limed plots than on those which had had no lime, but the gain for liming was very muchsmaller than in the experiments previously described, in which the lime had been applied to corn, two years before the clover seed was sown.

Neither in the wheat nor in the clover was any conspicuous difference observed between the effect of the quick-lime and that of the hydrated lime.

The experiments thus far described have been made on a somewhat sandy, clay soil, a soil which would be considered rather easy to work by farmers accustomed to heavy clays. The four crops of corn which have been harvested separately have been grown immediately after liming and have shown a considerable improvement in yield on the limed land as against that left without liming. There is reason to believe that the oats and wheat, following the corn in succession, were benefitted by the liming at least as much as the corn, while the clover, following the wheat, and sown two years after the application of lime, has shown a most conspicuous gain from the liming.

When the lime has been applied directly to wheat, however, the yield of the wheat crop immediately following the liming has been but little improved or even slightly reduced, but the second and third crops of wheat, grown continuously after liming, have shown a marked improvement. The evidence accumulated thus far, therefore, shows that *on this soil* lime requires two or three years to produce its full effect.

If on this soil, the physical texture of which seems to be fairly good, the chief function of lime is to produce conditions favorab e to the growth of the soil organisms, through the agency of which the organic nitrogen of the soil is converted into nitrates, and of the nodule-forming bacteria which prepare the free nitrogen of the soil for the use of the clover plant, we would have a plausible explanation of the effect of lime, as observed in these tests, since the multiplication of these soil organisms, to a sufficient extent to permeate the entire soil, would naturally require some time.

On the Station's test farm at Strongsville is a tract of about two acres of heavy, clay land, lying nearly flat and holding water for a long time, even after drainage. The soil of this test farm, like that at the main station, is of glacial drift origin, largely modified by the underlying rocks, which here are gray, argillaceous shales, belonging to the Waverly group. This soil is sufficiently rich in the mineral constituents of fertility for abundant crop production, but it holds its stores in so tight a grasp and deals them out in such niggardly portions that its profitable management is a difficult problem. The characteristic natural growth on this soil is Spiked Out-grass, *Danthonia spicata*, locally known as "Poverty grass", a grass which immediately covers the land when cultivation ceases. The crops grown on this land proved so unsatisfactory that it was finally sown to soy beans, these were plowed under in September, 1903, together with a liberal dressing of manure, and the whole was sown to wheat after one-half the land had been limed. The result was a yield of 7.26 bushels of wheat per acre on the unlimed, and 13.81 bushels on the limed land, with a fair stand of clover on the latter, in the fall of 1904, as against an almost complete failure on the former.

The object here was improvement of the soil texture, and it seems to have been at least partially accomplished.

LIME DOES NOT ALWAYS INCREASE THE YIELD.

On another portion of the Strongsville test farm a rotation is in progress duplicating the 5-year rotation at the main Station. Three successive corn crops in this rotation have been limed, after the same plan as that above described, the lime being applied to one-half of each plot. No effect whatever has yet been observed as due to the liming, either on the cereal crops or clover, the latter crop having failed so completely on all the land in the spring of 1904 that it was plowed under.

At the test farm at Germantown, which is located on a soil of glacial drift, overlying limestone, lime was applied to tobacco in 1903, the tobacco being followed by wheat in 1904. No decided effect from the lime is yet manifest in this case, although tobacco is one of the plants which the experiments of the Rhode Island Experiment Station have shown to be especially sensitive to lack of lime. At Germantown, also, lime appeared to have actually injured alfalfa, sown in the spring of 1904, but at the main Station and at Strongsville it has been found that alfalfa cannot be grown without first liming the soil.

At the Pennsylvania Experiment Station, which is located in Center County on a limestone formation, an experiment in the use of fertilizers, manure and lime on corn, oats, wheat, clover and timothy, grown in a four-year rotation, has been in progress since 1882. Two plots in this test receive lime, and a third ground limestone, applied to the corn crop at the rate of 2 tons per acre. On one plot lime is applied alone and on another it is used in connection with manure, the manure being first plowed under. The ground limestone has been used alone. The results of 20 years of this work are reported in the annual report of this Station for the year ending June 30, 1902, and show that lime, when used alone, has reduced the yield of corn, oats and grass, and but slightly increased that of wheat; when used with manure it has reduced the effect of the manure on corn, but increased its effect on the other crops. Ground limestone, as a rule, has produced better results than lime used alone, but its effect has been small.

THE INVESTIGATIONS OF THE RHODE ISLAND EXPERIMENT STATION.

The most extensive experiments on the liming of soils yet reported are those of the Rhode Island Experiment Station. These experiments have been in progress for 10 or 12 years, and have been made on sandy soils of granitic origin, on which clover has manifested similar behavior to that above described as shown on the land at the Ohio Station, and the liming of the soil has been found there, as here, to be the necessary treatment required to secure a normal growth of clover. Many other plants have also been grown at the Rhode Island Station, both with and without lime, and a fund of valuable information has thus been secured respecting the lime requirements of various plants. At the Rhode Island, as at the Ohio Station, the failing clover crop is immediately replaced by sorrel.

HOW TO DETERMINE WHEN LIME IS NEEDED.

The soil in Rhode Island on which lime has produced the most marked results shows a decided acid reaction under the chemist's tests, and attention has been especially directed to the detection of acidity, which is so readily done by the litmus test, as the ready and sufficient means of determining whether lime is needed.

The soil of the main Station at Wooster, on which the experiments above described have been made, is distinctly acid, and this is equally the case with the Strongsville soil, while the Germantown soil also shows a slight acid reaction. Until we have more definite knowledge in this direction, therefore, we would recommend a careful study of the clover crop as an index to the need of any particular soil for liming, rather than exclusive dependence on the test for acidity, although that also should be employed.

When the common red clover, after taking root in the spring, is found, later in the season, to be making no growth, and finally disappears in patches or altogether, then the need of lime is indicated. This condition of the soil is usually found in regions where the natural supplies of lime are scanty, the soils having been derived from sandstones or shales, and the small stores of lime reduced by long continued cropping. The appearance of the plant known as Sorrel, or Horse Sorrel, *Rumex Acetosella*, is a further indication of the need of lime. Usually this plant first appears on the higher and poorer portions of the field, and as it becomes more abundant it gives to these portions the peculiar color from which it derives its name. Such soils are usually found to give an acid reaction to the litmus test.

There are, however, other soils which may be improved by liming. Heavy, refractory clays, difficult to plow and breaking up into clods requiring much labor to pulverize, and producing a uniform and healthy appearing, but small and unsatisfactory growth of clover, followed by equally unsatisfactory yields of other crops, may be completely changed in character by a large dressing of lime. the lime opening them up to the action of the weather and putting them in such condition that clover will grow luxuriantly. And where clover attains its normal growth any other crop ordinarily cultivated in Ohio may be successfully grown. This is to say, not that the growing of clover will dispense with the use of manures or fertilizers, but that a luxuriant clover crop will leave the soil in such physical condition that manures and fertilizers will produce their full effect upon subsequent crops, and that it will supply a large part of the nitrogen required by one or two cereal crops following. But it must be remembered that clover provides only nitrogen from sources outside the soil itself, and that it really facilitates the exhaustion of the soil stores of phosphorus, potassium and lime, so that if soil fertility is to be maintained without impairment these stores must be replenished by fertilizing or manuring.

WHAT IS LIME?

Pure lime is a chemical compound of the elements calcium and oxygen, the two being united in the proportion of 40 parts by weight of calcium to 16 parts of oxygen. When exposed to the air this calcium oxide absorbs water, a process which may be hastened by wetting the lime, in which case the lime and water unite with great energy and the evolution of considerable heat, the lime breaking down into the fine, white powder, known as slacked or hydrated lime. In the process of slacking, lime absorbs about 32 per cent. of its weight of water.

When slacked lime is exposed to the air it absorbs carbonic acid and gradually changes to carbonate of lime, which is the condition in which it exists in limestone. Heating of the limestone drives off this carbonic acid, together with any water that may be present, leaving caustic lime, or calcium oxide. Pure carbonate of lime is a combination consisting of about 56 per cent. of lime and 44 per cent. carbonic acid.

In most limestones the lime is associated with magnesia, together with iron and other impurities. Magnesia is as necessary to plant growth as lime; it is probably equally effective with lime in the neutralization of soil acidity and in the amelioration of the physical condition of the soil; so that, for ordinary agricultural purposes, the proportion of magnesia in a limestone is a matter of no consequence.

It is true that, under certain conditions, an excess of magnesia may be hurtful to vegetation, and it would not be advisable to use a pure salt of magnesia as a fertilizer on this account; but it has been shown that as long as lime is in excess of magnesia no injurious results follow its use.

THE KIND OF LIME TO USE.

Where neutralization of acidity is the only object sought in the use of lime it is probable that the pound of actual lime, or lime and magnesia combined, is equally effective, whether employed as quicklime, as slacked or hydrated lime, or as carbonate of lime; but it should be remembered that, in order to get as much actual lime as is contained in a ton of quicklime, we must use 2640 pounds of hydrated lime or 3570 pounds of carbonate of lime.

Where the object to be attained is the improvement of the texture of the soil, then quicklime will no doubt be found to be decidedly the most effective material.

Following is the composition of the two kinds of lime which have been used in the experiments above described, as determined by J. W. Ames, Chemist to the Station:

	Quicklime, per cent	Hydrated lime, per cent
Calcium oxide	54.69	61.62
Calcium carbonate	1 31	3 95
Magnesium oxide	39.93	3.06
Total lime and magnesia	**95 93**	**68.63**
Insoluble matter	1 18	6 01
Oxides of iron and alumina	1 15	4.95
Water and undetermined	1.74	20 41
Total	100 00	100.00

The quicklime cost $5.12 per ton in carloads, the hydrated lime is offered at $6 per ton in carloads, freight paid to Wooster in both cases. Hydrated lime, however, is being pushed on the market through agents who are asking $10 per ton for it in small lots. The actual value of the two limes for agricultural purposes is probably measured by their total content of lime and magnesia.

HOW TO APPLY LIME.

One way of applying lime is to distribute the freshly burned, lump lime in small piles over the field, after the land has been prepared for the crop, throw a little water on the lime, cover it with fine earth, and after it has thoroughly slacked mix it with more earth and distribute with the shovel. Half a peck of lime to the square rod would give 20 bushels, or 1400 pounds, to the acre. As lime absorbs nearly one fourth its weight of water (24 per cent.) in slacking, this would give about 1750 pounds of slacked, or hydrated lime per acre.

Slacked lime is a disagreeable material to handle, but it is sometimes applied in this condition, being spread from wagons; but any method of hand spreading involves irregularity in distribution and therefore a waste of material. Slacked lime may be successfully spread with the ordinary manure spreader, by first placing a quantity of litter on the spreader apron to prevent the lime from sifting through and to bring it within reach of the teeth of the spreader, and setting the apron to travel slowly. It is very difficult to spread lime satisfactorily with the ordinary fertilizer drill, because the fine powder packs above the feeders, and fails to run out evenly. Moreover, these drills are not usually made of sufficient capacity to apply more than about 500 pounds of material per acre.

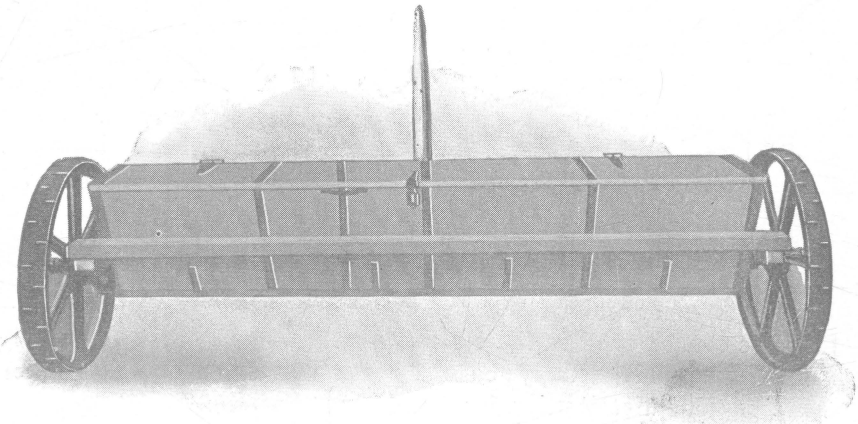
The best form of lime for this work is the ground quick-lime which is now made by several manufacturers for building purposes, it being more convenient to handle in this form than in lumps. Such lime can be used in the fertilizer drill when fresh and coarsely ground, though it usually contains considerable fine dust which interferes with distribution by that implement.

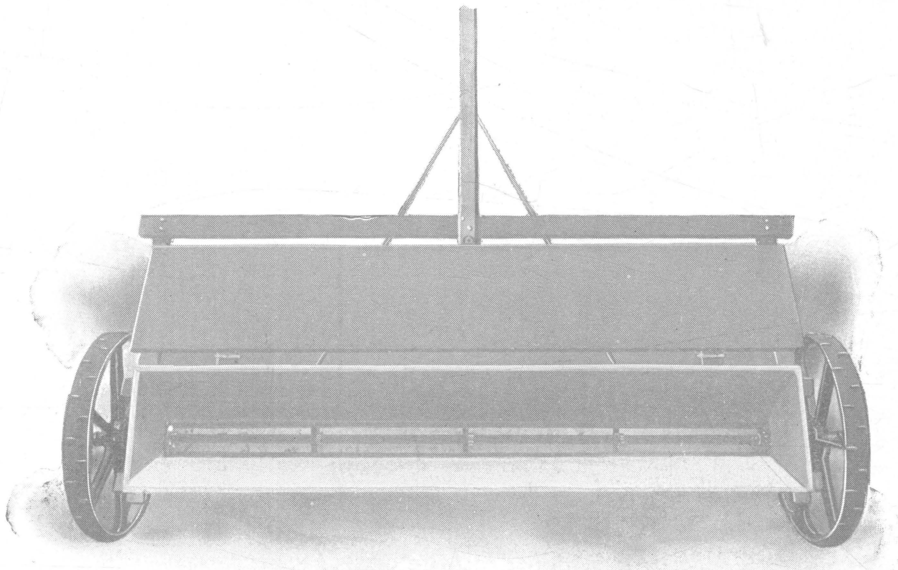
The most satisfactory implement for distributing lime is one made especially for that purpose. Such machines are made by several manufacturers of fertilizer drills. We have found a home-made lime spreader in use in Stark County, Ohio, and give the following directions for making it:

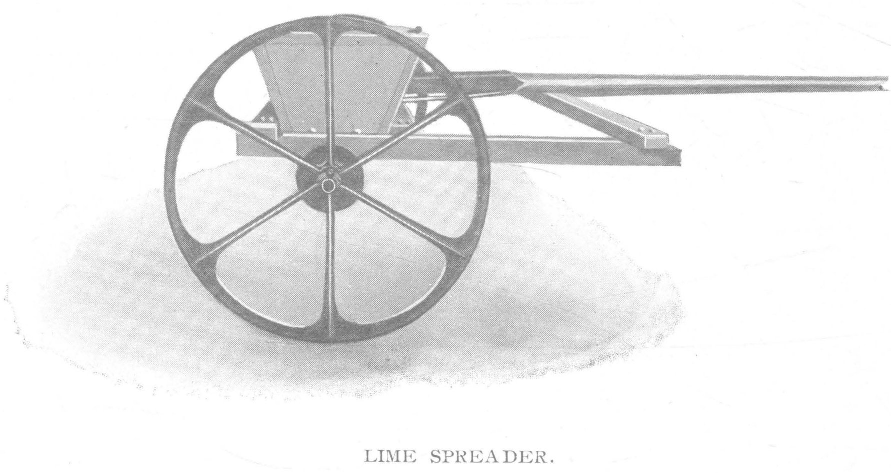
TO MAKE A LIME SPREADER.

Make a hopper, similar to that of an ordinary fertilizer drill, except that it should be 8, or more, feet long with sides and top 18 to 24 inches wide. For the bottom get two pieces of heavy, galvanized sheet iron, 6 inches wide and as long as the hopper; have a row of holes cut in the middle of each piece, the holes being one inch wide by 2 inches long and 8 inches apart. Cut the holes so that they will register. Fasten one strip to the hopper, as a bottom. Let the other strip slide under the hopper, moving upon supports made by leaving a space for it above bands of strap iron, which should be carried around the hopper every two feet to strengthen it. To this under strip, or plate, rivet a V-shaped arm, extending an inch in front of the hopper, with a half inch hole in the point of the V, in which drop the end of a strong lever, bolting the lever loosely but securely to the side of the hopper, 3 or 4 inches above the bottom. Let the lever extend 6 or 8 inches above the top of the hopper, and fasten to the top of the hopper a guide of strap iron, in which the lever may move freely back and forth. The object of this lever is to regulate the size of the openings by moving the bottom plate. Make a frame for the hopper, with a tongue to it, similar to the frame of an ordinary grain drill.

Get a pair of old, mowing machine wheels, with ratchets in the hubs and two pieces of round axle of sufficient length to pass through the wheels and frame and into the ends of the hopper, where they are welded to a bar of iron 1¼ inch in diameter and the length of the inside of the hopper. The axles should be fitted with journals, bolted to the underside of the frame.







LIME SPREADER.

Make a reel to work inside of the hopper by securing 8 short arms of ¼ inch by ¾ inch iron to the axle, and fastening to these 4 beaters or wings of ¼ inch by ⅝ inch iron, and about an inch shorter than the inside of the hopper, the reel being so adjusted that the wings will almost scrape the bottom of the hopper but will revolve freely between the sides. These arms may be made of two pieces, bent so as to fit around the axle on opposite sides, and secured by small bolts passing through the ends and through the beater which is held between them. The diameter of the completed reel is about 5 inches and its length an inch or so less than that of the inside of the hopper. This reel serves as a force feed.

Tack two pieces of oilcloth to the bottom of the hopper, one in front and one behind, of sufficient width to reach the ground. These are to reduce the annoyance to man and team of the flying lime dust.

SUMMARY.

The experiments reported in this bulletin have been conducted upon three types of soil, all of which owe their chief characteristics to the underlying geological strata, but all have been more or less modified by glacial agencies, namely:

1. The light, somewhat sandy clay of the farm of the main Station, in Wayne County, lying upon the upper, shaly sandstones of the Waverly series. This soil has been under exhaustive cropping for many years, and though requiring liberal manuring or fertilizing for the production of profitable crops, it responds promptly to such treatment.

2. The cold, heavy clay of the test farm at Strongsville, Cuyahoga County, overlying argillaceous shales, also of the Waverly series. A soil well stored with the mineral constituents of fertility, but holding to its stores with a stubborn grip.

3. The worn, clay soil of the test farm at Germantown, Montgomery County, the surface weathering of a heavy sheet of glacial drift, the drift lying upon limestone rocks and largely composed of the detritus of such rocks with some intermingling of materials derived from granites and shales. A soil typical of the upland clays of the Miami Valley.

On the first of these soils it has been increasingly difficult to grow clover during recent years. A good stand may be secured in the spring, but it makes a feeble and irregular growth, and finally much of it disappears altogether, leaving patches of moderately vigorous clover, interspersed with patches of sorrel. This soil shows a decided acid reaction, especially on the spots where the clover fails.

On the second soil the growth of clover has been small, but it has not been so irregular as on the first, nor has there been any marked growth of sorrel. The characteristic weed plant on this soil is the grass known as Spiked Oat-grass. This soil also is decidedly acid.

On the third soil clover is still making a regular growth. The available fertility is low, as indicated by the yield when unfertilized, but the soil readily responds to manuring and fertilizing. This soil is slightly acid, but the reaction is not so decided as is the case with the other two.

These experiments are, as yet, only begun, and the conclusions indictated by their results thus far must be held subject to future revision. A few points, however, seem to be so clearly brought out that they may safely be acted upon. These are as follows:

1. On the soil of the main Station, naturally somewhat deficient in lime because of its origin, the condition unfavorable to clover is aggravated by the use of fertilizing materials originally compounded with acid, such as acid phosphate, potassium chloride and ammonium sulphate, although these materials are by no means the sole cause of this condition.

2. On this soil a luxuriant growth of clover has been secured by the use of lime, *in conjunction with* materials carrying *both phosphorus and potassium*. Lime alone, though increasing the growth of clover somewhat, does not produce a full yield, nor does such a yield follow the use of lime in association with a carrier of phosphorus only, or of potassium only. When the lime has been applied to the corn crop, two years before the clover seed was sown, the corn being followed by oats and wheat, the effect on the clover has been much better than when the lime was applied to the wheat crop the fall before sowing the clover seed.

Among the points suggested by these experiments, but which require further investigation, are the following:

1. When lime has been applied directly to the wheat crop it has sometimes reduced the yield of wheat. When an increase of wheat has immediately followed liming the gain seems to have been largely due to the opening up of a refractory clay soil by the lime.

2. A ton of lime to the acre has been sufficient to produce a luxuriant growth of clover at the main Station, together with a considerable increase in the cereal crops preceding the clover. It is possible that a smaller quantity would have sufficed. On this point investigations are in progress. At the Strongsville test farm, however, the present indications are that a much larger quantity of lime may be required.

3. Thus far, the effect of lime at the Germantown test farm has been negative, if not actually injurious.

4. No superiority has yet been discovered in "hydrated" lime over ordinary lime.